PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Method and apparatus for the Treatment of Finely Divided Fluidizable Solid Material

ERRATA

SPECIFICATION No. 736,036

Page 1, Index at acceptance, line 3, *for* "642)," *read* "64(2)"

Page 2, line 66, *after* "alternatively" *insert* ","

Page 3, line 11, *after* "now" *insert* "more"

Page 10, line 86, *for* "on" *read* "of"

THE PATENT OFFICE,
6th February, 1956

(1) Most of the sensible heat remaining in the exhaust gases is practically impossible to recover economically and is therefore wasted.

(2) Gases evolved when treating sulphide ores and the like gas evolving materials are diluted by the heating gases, thus increasing the cost of their recovery in the form, for instance, of dilute or concentrated acids.

(3) The material undergoing treatment always becomes contaminated to a certain extent with combustion products from the heating medium. While this is in some cases not an important factor, it becomes important where the product being produced is to be of high purity.

There has accordingly been a demand in the art for a means of heating finely divided solid materials not subject to the above disadvantages, but up until the present time it has been found imprac-

large scale operation and which may be easily adapted to produce the optimum rate of heating of the materials undergoing treatment and in which gases produced during the various stages of the heating operation may be withdrawn separately to provide for the economic recovery of useful components thereof.

Other objects and advantages of the present invention will be apparent as the specification proceeds.

With the above objects in view the present invention, broadly speaking, consists in a method of treating finely divided fluidizable solid material comprising forming and maintaining a deep fluidized bed of said material in horizontal flow and transmitting heat to said material by means of heating elements in direct contact therewith at successive stages of its horizontal flow in varying predetermined quantities and at varying predetermined temperatures.

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COMPLETE SPECIFICATION

Method and apparatus for the Treatment of Finely Divided Fluidizable Solid Material

We, ALUMINIUM LABORATORIES LIMITED, a Corporation organized under the laws of Canada, of 1800, Sun Life Building, in the City of Montreal, in the Province of Quebec, Canada, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method and apparatus for the treatment of finely divided, fluidizable, solid material.

Calcining operations on finely divided solid materials have, until the present, generally been carried out in rotary kilns with direct heat exchange taking place between combustion gases and the particles of solid material. While this method is satisfactory for many uses, it suffers from a number of disadvantages, three of the main ones being:—

(1) Most of the sensible heat remaining in the exhaust gases is practically impossible to recover economically and is therefore wasted.

(2) Gases evolved when treating sulphide ores and the like gas evolving materials are diluted by the heating gases, thus increasing the cost of their recovery in the form, for instance, of dilute or concentrated acids.

(3) The material undergoing treatment always becomes contaminated to a certain extent with combustion products from the heating medium. While this is in some cases not an important factor, it becomes important where the product being produced is to be of high purity.

There has accordingly been a demand in the art for a means of heating finely divided solid materials not subject to the above disadvantages, but up until the present time it has been found impractical to do this except on a very small scale or at very high cost.

The present invention has as a principal object the provision of a method of and apparatus for heating solid materials in granular and powder form by means of heating elements in direct contact with said materials,

It is also an object of the invention to provide such a method and apparatus which provides for efficient recovery of the excess heat contained in the products produced therein.

It is a further object of the invention to provide a method of and an apparatus for the high temperature treatment of comminuted solid materials in which a product free from contamination from outside sources may be produced.

It is a still further object of the invention to provide a method of and an apparatus for heating comminuted solid materials which is adapted for continuous large scale operation and which may be easily adapted to produce the optimum rate of heating of the materials undergoing treatment and in which gases produced during the various stages of the heating operation may be withdrawn separately to provide for the economic recovery of useful components thereof.

Other objects and advantages of the present invention will be apparent as the specification proceeds.

With the above objects in view the present invention, broadly speaking, consists in a method of treating finely divided fluidizable solid material comprising forming and maintaining a deep fluidized bed of said material in horizontal flow and transmitting heat to said material by means of heating elements in direct contact therewith at successive stages of its horizontal flow in varying predetermined quantities and at varying predetermined temperatures.

The invention also consists in apparatus for treating finely divided, fluidizable solid material, comprising means for providing a deep (that is to say having a depth substantially greater than the width thereof), horizontally flowing fluidized bed of said material, said means including a refractory tunnel having a height substantially greater than the width thereof and provided with a gas-permeable bottom and means for introducing thereinto through said gas-permeable bottom a fluidizing medium in controlled amounts, means for feeding comminuted material to one end of said tunnel near the bottom thereof, means for withdrawing treated material from the other end of said tunnel at a point somewhat below the top thereof, means for withdrawing gaseous products from the top of said tunnel; and heating means in direct contact with the material to be treated along at least a part of the length of said tunnel, the heat supplied thereby preferably being calculated to supply heat to said material in amounts and at temperatures corresponding to the heat requirements curve of said material for the operation being performed.

Suitably the apparatus of the invention may be connected to a suitable cooling apparatus, or the tunnel may be divided into two or more zones, in the latter of which means may be provided for cooling the material undergoing treatment and recovering the heat contained therein. The cooling section may contain cooling coils through which is circulated a fluid-cooling medium, and this section of the tunnel may be suitably somewhat wider than the heating section of the tunnel. The cooling may, for instance, be effected substantially in accordance with the teachings of copending application No. 15,151, filed June 26th, 1951 (Serial No. 693.868), and separation of the one zone from the other may suitably be effected by means of zoning devices of the type described in copending application No. 1801/53, filed January 21st 1953.

Where the apparatus is designed for the treatment of materials which evolve gaseous products during the treatment, it may be desirable to divide the heating zone of the tunnel into a number of sections in order separately to extract the gases evolved over a number of temperature ranges to produce sufficiently concentrated gaseous products from which valuable components are recoverable.

For low temperature calcination operations the heating elements may consist of steam or hot gas pipes arranged in suitable manner within the tunnel or, alternatively the heating elements may be electrical resistors.

For high temperature calcination operations, the heating elements will consist of electrical resistors or radiant wall surfaces.

Where electrical resistor heating elements are used it is preferred to arrange these in vertical banks of horizontally disposed transversely extending elements, which may be removed from the apparatus through a suitable hatch in the top thereof. In a preferred form of the apparatus, several banks are connected together in a crib-like arrangement and fed by common vertical distributor bars connected to overhead bus-bars and serving as a suspension for the cribs. The advantage of this arrangement is that for each crib there are only two sources of heat leakage from the tunnel.

The design of the resistor elements themselves is of importance in obtaining the best possible results. The preferred form of resistor element is a strip resistor which is mounted with its major plane inclined at an angle to the horizontal, the downstream edge of the element being uppermost, all of which will be described in greater detail and will be more fully understood from the following detailed description of a number of embodiments of the invention taken in conjunction with the accompanying drawings wherein:—

Figure 1 is a longitudinal vertical section of an apparatus according to the invention designed for low temperature calcination and recovery of the sensible heat contained in the product of calcination, the heating elements being steam pipes.

Figure 2 is a transverse cross-section of the apparatus shown in Figure 1, taken along the line 2—2.

Figure 3 is a fragmentary top plan view of the apparatus shown in Figure 1, illustrating the general arrangement of the cooling section thereof.

Figure 4 is a cross-section of an apparatus according to the invention designed for the roasting of sulphide ores, illustrating how the heating portion of the tunnel may be divided into a plurality of zones for purposes of keeping the gases from the several zones separate.

Figure 5 is a longitudinal section of a kiln according to the invention illustrating the use of strip type electrical resistor elements arranged in cribs containing multiple vertical banks of resistors.

Figure 6 is a longitudinal section similar to Figure 5 but illustrating the separation of the calciner into zones;

Figure 7 is a cross-section taken along the line 7—7 of Figure 6,

Figure 8 is a diagrammatic vertical longitudinal section through the bed and a strip resistor illustrating the flow of gas and solids past the element;

Figure 9 is a graph of the heat requirements per 100° F. temperature rise in the calcination of gibbsite, and

Figure 10 is a horizontal section illustrating a suitable layout for a calcinning plant according to the invention.

Referring now particularly to the drawings, the kiln illustrated in Figures 1, 2 and 3 is particularly adapted for low temperature calcination. The kiln consists essentially of an elongated tunnel rectangular in cross-section formed by the refractory side walls 10 and 11 and the refractory top 12 and bottom 13. The refractory portions of the kiln are, of course, supported by a suitable supporting structure which is not shown in the drawings for purposes of simplicity of illustration. The supporting structure may, of course, be of any conventional design and construction.

The tunnel is provided with the gas-permeable membrane 14 parallelling the bottom thereof and running from end to end thereof. The gas-permeable membrane may be composed of any material permeable to gases but impermeable to the finely divided material which is to undergo treatment, and is of sufficiently refractory character to withstand the temperature encountered during the calcination process. It may, for instance, be a wire screen supported on a heavier wire grid, or be a sandwich consisting of one or more layers of asbestos cloth between layers of wire gauze. In high temperature kilns it may be desirable to use a porous refractory material. In general, however, for medium and low temperature operations wire gauze, or a wire gauze-asbestos sandwich arrangement, will be preferred. The tunnel is provided at one end with a feed bin 15 communicating with the interior 16 of the tunnel through the space 17 below the underflow baffle 18. The bottom 19 of the feed bin is slanted so that material within the feed bin 15 will flow by gravity into the interior 16 of the tunnel. Suitable means (not shown) are provided for supplying material to undergo treatment at a predetermined rate to the feed bin 15.

At the other end of the tunnel is mounted a discharge bin 20 which communicates with the interior 16 of the tunnel through the space 21 above the overflow baffle 22. The bin 20 is provided with a suitable delivery chute 23.

The tunnel is divided into a heating zone A and a cooling zone B, by means of a separating baffle 24 which extends from the roof of the tunnel to a point below the normal level of the top of the material undergoing treatment within the tunnel and by the separating baffle 25 extending between the walls 10 and 11 of the tunnel and leaving a space 26 between it and the separating baffle 24 and a space 27 between the bottom thereof and the membrane 14. The separating baffle 28 separates the space within the tunnel below the porous membrance 14 into two chambers A^1 and B^1. Inlet ports for fluidizing medium to chambers B^1 and A^1 respectively are provided in the bottom 13 of the tunnel, as at 29 and 30, and preferably the fluidizing medium conduit 31 connecting to the inlet 30 is fed through a heat exchanger (illustrated diagrammatically at 32). Separate exhaust stacks for each of the chambers A and B are provided respectively by the stacks 33 and 34, while a further exhaust stack 35 may be provided in the top of the discharge bin 20. The system for supplying fluidizing medium to the inlet ports 29 and 30 is provided with the usual means (not shown) for controlling the rate of delivery of fluidizing medium to the chambers B^1 and A^1 respectively, and such means are arranged so that the amounts of fluidizing medium delivered to each of the chambers B^1 and A^1 can be independently controlled.

Within the heating zone A are situated the steam pipes 36 which may suitably be mounted in banks between steam headers 36a substantially as illustrated in Figure 2. The width of the tunnel is governed principally by the fluidized flow characteristics of the material undergoing treatment and will be wide enough to eliminate the possibility of surface phenomena along the sidewalls interfering with the smooth flow of the material, while the tunnel should not be wide enough to allow cross-currents and eddies to develop. In general, the tunnel will be between about one foot and six feet in width. The height of the tunnel of the heating zone should be greater than the width thereof and generally will be about 6 to 7 feet. In principle the tunnel could have a height as low as 3 feet, but since the bed in such a shallow tunnel would have unfavourable heat exchange characteristics, it is preferable in all but the smallest of installations to design the tunnel so that it has a height of at least five feet.

The banks of heating elements 36 are so arranged in spacing and density as to produce substantially the optimum rate of heating for the particular material being calcined. If no changes of phase are occurring the temperature at any

point within the tunnel will be a function of the distance from the inlet end as well as of the thermal properties of the material to be heated and the horizontal bed velocity of the material passing through the apparatus. Where changes of phase involving absorption or emission of energy are occurring, the increased or decreased amount of heat required can either be calculated from existing data or determined empirically. Thus it is possible to calculate the temperature and heat requirements at any point in the tunnel with a considerable degree of accuracy, and design the apparatus accordingly.

The spacing of the heating elements will thus be denser in regions of the apparatus corresponding to ranges of temperature where more heat is required, for instance, because of endothermic phase changes in the material and *vice versa*. In practice it is possible to design the arrangement of heating elements so that the quantity of heat supplied at various temperatures corresponds closely to the heat requirement curve of the material being treated for any particular operation. In zones where no phase changes are taking place the spacing of the heating elements is governed by the heat capacity (i.e. specific heat times weight) of the material in those zones.

It will be understood that, if desired, the heating zone may be divided into two or more sections by means of zoning devices of the type used to separate the heating and cooling departments. Such an arrangement may be convenient if the type of or amount of gas evolved during heating changes as the temperature of the material increases.

The cooling zone B of the tunnel may be somewhat wider than the heating zone A in order to shorten the length of the apparatus and provide a certain amount of freedom in the arrangement of heat exchange elements therein. In Figures 1 and 3 the cooling zone B is illustrated as having a series of banks of heat exchange elements 37 consisting of buckled tubings, through which a fluid heat exchange medium may be circulated.

The apparatus thus far described operates in the following manner. Fluidizing medium, which may be air, flue gas or any desired vapour or gas, is fed to the chambers A^1 and B^1 and passes upwardly through the membrane 14. The comminuted material to be treated is fed to the feed bin 15 and passes beneath the underflow baffle 18 under the influence of gravity and flows out over the membrane 14. However, the fluidizing medium passing upwardly through the membrane 14 fluidizes the material flowing into the interior 16 of the tunnel from the feed bin 15, reducing its natural angle of repose to substantially zero, and causing it to flow substantially like a liquid, so that it fills the space 16 within the tunnel until the level of the top of it exceeds the level of the overflow baffle 22 at the outlet end of the tunnel, at which point the level of material in the tunnel will remain substantially constant, and the material will be continually overflowing through the space 21 into the bin 20 at the same rate as material is being fed to the feed bin 15. Thus a deep horizontally flowing fluidised bed 38 is built up within the tunnel. The depth of the bed should in general be approximately two-thirds to three-quarters of the total depth of the tunnel, and because of the continual feeding of fresh material to the bed and withdrawing of material from the outlet end of the bed, the whole bed will be continually moving horizontally towards the outlet end at a rate depending upon the rate of feed.

The state of subdivision of the feed material may vary considerably. Materials as coarse as 5 mesh (U.S. Standard Screen) may be treated in an apparatus of this character. However, it is preferred to have the feed material comminuted to a state of subdivision below 20 mesh.

As the material proceeds through the heating zone A it becomes heated by the heating elements 36. In the case of moist or hydrated materials, the water is driven off in the form of steam. Since this steam will itself act as a fluidizing medium, it is desirable to regulate the flow of fluidizing medium to the chamber A^1 in such a way that the combined fluidizing effect of the fluidizing medium passing through the membrane 14 and the steam produced during the calcination is essentially uniform along the length of zone A. Thus, for example, chamber A^1 may, if desired, be divided into two or more chambers and the rate of input to each chamber adjusted to achieve the desired uniformity of total fluidizing effect.

The separating baffle 24 extending below the surface of the bed 38 forms a seal confining the heated fluidizing medium in the space 39 above the bed in zone A, so that it may be withdrawn separately through stack 33 and the heat therein may be recovered in the form of process steam or in any other desired manner, as for instance, by using it as a heat exchange medium in the heat exchanger 32 to heat the inflowing fluidizing medium in conduit 31.

At the downstream end of zone A the

material undergoing treatment as a hot, calcined product flows through the spaces 26 and 27 into the cooling zone B, where it is cooled by means of banks of cooling coils 37.

It will be appreciated that the cooling of the hot material may be accomplished otherwise than in a section of the tunnel such as section B described above. It may, for instance, be desired to cool the calcined material in conventional manner or to pass the material from section A over an over-flow baffle and then a vertical shaft to a cooling tunnel of the type described in said copending Application No. 15,151/51 (Serial No. 693,868). Accordingly, it is to be understood that the illustration herein of the calciner being mounted in connection with a cooling section is given as an example only of one of a preferred method of putting the invention into practice. Various other arrangements of calciners according to the invention will be obvious to those skilled in the art.

The heat recovered in the cooling medium flowing through the coils 37 may be used for various purposes, for instance, for the production of process steam or otherwise, as desired. Finally, the cooled, calcined product overflows the overflow baffle 22 and is discharged through the delivery chute 23 for bagging or further processing, as the case may be.

The apparatus illustrated in Figure 4 is a good example of the manner in which apparatus according to the invention may be arranged or modified to take advantage of favourable factors developing during the treatment of certain materials. The apparatus illustrated is designed for the roasting of sulphide ores, and it differs from that illustrated in Figures 1, 2 and 3 mainly in the division of the heating section into two separated zones and the provision of electric heating elements instead of steam or gas pipes.

The main components of the fluidizing trough are similar to those in Figures 1, 2 and 3 and are indicated by like reference numerals.

As shown, the apparatus is divided into a preheating zone C, a roasting zone D and a cooling zone E by zoning devices of the type described in Application No. 1801/53, filed 21st January, 1953.

Each of these devices consists of an overflow baffle 40 and an underflow baffle placed in parallel spaced apart relationship to the overflow baffle on the downstream side thereof (that is to say, on the side thereof remote from the feed end of the apparatus). The impermeable blocks 42 prevent entry of fluidizing medium below the space between the baffles 40 and 41. As described in Application No. 1801/53, filed 21st January, 1953, these zoning devices effectively isolate the solid materials and gases in each zone from those in the other without materially interfering with the horizontal flow of the fluidized solids through the apparatus. As shown by the lower level of the bed surface on the downstream side of each zoning device, however, these devices do result in a slight loss of head, but this is immaterial to the operation of the apparatus.

The space between the membrane 14 and the bottom 13 of the apparatus is divided into separate gas chambers C^1, D^1 and E^1 by the panels 28 which are situated beneath the impermeable blocks 42. To the chambers C^1, D^1 and E^1 are fed different fluidizing gases *c*, *d* and *e*, respectively, from independent sources.

Within the tunnel and arranged so that they will be totally submerged in and distributed throughout the fluidised bed are the electric resistance heating elements 43. These are arranged crosswise of the bed and may be of any suitable type in accordance with the design requirements of the apparatus and the temperatures to which they are to be heated. They may, for instance, be of tubular or bar form, or may be of the flat strip type. They may be mounted in any convenient manner, but preferably will be mounted in the manner illustrated in Figures 5, 6 and 7, which manner of mounting will be described later. They may be formed from any suitable metal, but where the temperature is high, or corrosive gases or vapours are evolved, they may be formed from silicon carbide or other like temperature or corrosive resistant material. The resistors 43 will be suitably electrically connected to provide for independent control of the power supplied to the elements in zones C and D.

Metallic ores containing sulphides in quantities not high enough to provide for their complete calcination by the exothermic oxidation of the sulphides may be treated according to the invention with particular advantage, and the operation of the apparatus illustrated in Figure 4 will be described with reference to the treatment of this type of ore, although it will be appreciated that such apparatus may be used in many other applications.

The ore is fed to the feed bin 15 and enters zone C of the apparatus through the opening 17 under the underflow baffle 18, where it becomes fluidized in the manner previously explained and forms itself into a horizontally flowing

fluidized bed. The gas *c*, which is used to fluidize zone C, will in this case be an inert gas such as nitrogen, carbon dioxide or flue gas. Sufficient heat is supplied by heating elements 43 in zone C to bring the temperature of the material being treated up to a point just below that at which the exothermic oxidation of the sulphide particles becomes self-initiating.

The hot materials then flow over the overflow baffle 40 and downwardly under the influence of gravity, entering zone D through the space beneath the underflow baffle 41. The fluidizing gas *d*, which is supplied to zone D, is a mixture of air and a portion of the exit gas d^1 drawn off from the top of zone D, and, as the material proceeds through zone D, its temperature is raised to the point where the exothermic oxidation of the sulphide particles takes place. The amount of heat supplied to this zone is calculated to bring the oxidation to completion. Part of the exit gases d^1 are recirculated with the fluidizing medium in zone D in order to bring the concentration of the SO_2 in gas d^1 to the highest possible point, and only sufficient air (or oxygen) is supplied to enable completion of the oxidation reaction. The main body of the gas d^1 can be used for the production of sulphuric acid. Thus, by the use of the invention a concentration of SO_2 in the exit gas can be obtained, which is otherwise impossible when roasting ores of this type, thereby permitting the production of sulphuric acid as a by-product and enabling economic processing of ores which would otherwise be of marginal value.

The power consumption in this type of application depends on the composition of the ore, and may be limited to a few Kilowatt hours per ton of calcined product which can be largely recovered in the form of process steam developed from the cooling medium circulating through coils 37 in zone E of the apparatus.

In Figures 5, 6 and 7 illustration is given of how the heating elements may be arranged in multiple vertical banks of crib-like structure. It will be seen that the same general structure for producing a deep horizontally flowing fluidized bed of the material being treated is utilized as in the embodiment of the invention previously described. The embodiments illustrated in Figures 5, 6 and 7 will therefore be described only insofar as they differ from those illustrated in Figures 1—4.

In the apparatus illustrated in Figure 5 the heating zone F is separated from the cooling zone G only by the underflow baffle 50. This apparatus is designed primarily for the treatment of materials where the changes in condition of the material during its treatment do not lead to the evolution of potentially valuable gases, and there is therefore no need to effect an accurate separation of the gases in the heating zone and those in the cooling zone, while gases of similar composition may be used as fluidising media in both zones. Obviously such an arrangement can be used only if the pressures on the chambers F and G are substantially the same. If the transfer of fluidizing medium between chambers becomes too great, zoning devices as shown in Figure 4 should be used. It will also be observed that the gas chamber below the heating zone F is divided into two independently supplied chambers F^1 and F^{11} by partition 51. This is done so that the amount of fluidizing medium supplied may be varied to suit conditions as the material proceeds through zone F. It may be desirable to vary the amount of fluidizing medium supplied for various reasons. One of these, as has already been mentioned, is that if a gas is evolved from the material during heating thereof, this gas will itself act as a fluidizing medium once it is set free, making the requirements of added fluidizing medium less in that portion of the apparatus where the evolution of gas is occurring. Another reason is that, as is well known in the art, the "viscosity" of the bed will decrease as more fluidizing medium is supplied. Since the resistance to flow of the apparatus may vary from portion to portion, either because of changes in the density of the arrangement of the heating elements or changes in the nature of the material being treated, it may be desirable to adjust the amount of fluidizing medium supplied in a manner allowing for the variation in resistance to flow so that the head of material within each zone is as uniform as possible throughout the length of the zone. It should also be pointed out that dusting losses occurring because of entrainment of finer particles of material in the exit gases will be greater for higher space velocities of fluidizing medium within the bed and above it. Accordingly it will be desirable to maintain at all times as low a space velocity as is possible consistent with efficiency of the heating and cooling operations being carried out. In practice it has been found possible by proper control of space velocities to reduce the dusting losses in the treatment of such readily entrainable materials as powdered alumina to as low a value as about 6%, while still maintaining a sufficiently low "viscosity" within the bed to permit efficient carrying out of the calcining

operation. The ideal space velocities will, of course, vary from material to material and will depend also to some extent upon the particular apparatus concerned. It is however, a simple matter to determine this in practice for any particular set of conditions.

The heating elements 52 in the apparatus illustrated in Figures 5, 6 and 7 are arranged in multiple vertical banks, each bank being flanked on each side and supplied with power by a vertical distributor bar 53. These distributor bars are connected at their upper ends to the branch bus-bars 54, which are fed by the vertical bus-bars 55 connected centrally thereto and which connect at their upper end to main power bus lines (not shown) situated above the apparatus. The proper spacing between the vertical distributor bars on either side of the heating elements 52 is maintained by the insulated spacers 56 which extend between the end distributor bars of each "crib" or group of banks. Each "crib" may be suitably supported in the tunnel by ceramic block supports consisting, for instance, of the blocks 57 beneath the membrane 14 and blocks 58 above the same. The cribs, however, will only require support beneath the end distributor bars, and in general the area of support will be as small as possible so that influx of fluidising medium is interfered with only to a minimum extent.

The roof of the tunnel is formed from ceramic blocks, and these are arranged in such a way as to form removable hatches 59 directly above the cribs of heating elements so that for purposes of servicing and maintenance the cribs can be removed upwardly through the hatches without having to dismantle the apparatus as a whole.

The arrangement of the heating elements in multiple banks or cribs as set forth has many advantages. In the first place, of course, it provides for easy removal and adjustment of the heating elements, making it possible to vary the arrangement, density and heat delivery of each portion of the apparatus without having to rebuild the whole. Thus a greater versatility in operation is afforded. Very important from a heat economy point of view, however, is the fact that with only two buses passing through the roof of the tunnel for each crib, there are a very small number of sources of heat leakage from the apparatus. This results in increased economy of operation, particularly insofar as high temperature operations are concerned.

The heating elements 52 may be of any suitable design. From the point of view of simplicity, availability and cost, it is most advantageous to utilize strip resistors, but it was at first believed that this would be impossible because of the nature of the operation being carried on. If strip resistors are placed with their flat surfaces in the horizontal plane, the area above them is masked from the fluidising medium and unfluidized material will deposit on the top of the elements. This will be mostly moved off as the bed advances horizontally, but a considerable amount remains permanently on the top of each element. At the same time, an air pocket forms under each resistor. Not only is the life of the elements greatly reduced in this manner, but the whole fluidizing operation is upset. It will be appreciated that if flat resistors are disposed with their flat surfaces in the vertical plane, their combined resistance to horizontal flow of the bed becomes much too great for practical operation.

We have found, however, that if the flat surfaces of the resistors are inclined with their downstream edges above their upstream edges at a certain angle to the horizontal, both the solids and the gas move past the strip at a very fast rate, as is illustrated in Figure 8, and the adverse effects previously mentioned are overcome. Experimentally it has been found that if the angle of inclination of the strips is between 75° and 45° to the horizontal, the elements may be arranged in a density as great as 48 lineal feet of elements (1 inch wide) per cubic foot of bed without interrupting the smooth flow of solids through the bed or materially interfering with the fluidizing operation. In order to achieve best results, it is important to ensure that the horizontal bed velocity is fairly high, since, as will be appreciated, the slower this velocity, the more pronounced are the difficulties described above. Bed velocities between 0.2 to 5 feet per minute have been found to be desirable in connection with use of the apparatus with tubular heating elements, while when using strip resistors, as above set forth, it has been found desirable to design the equipment with a bed velocity in mind in the upper part of this range. The upper limit of 5 feet per minute is by no means critical insofar as operability is concerned, but is given here merely as an example of a desirable upper limit from the practical standpoint. The reason that it is not desired to go beyond this velocity is simply that the higher the horizontal velocity of the bed becomes, the longer the heating zone must be to enable the required heat to be transferred to the material passing through it. Operations at higher bed velocities are

quite feasible, but are generally speaking apt to be uneconomical having regard to the higher capital cost of equipment per unit of capacity, and the greater area available for heat radiation and conduction losses.

It should be pointed out that, while the heating elements illustrated herein are generally disposed horizontally across the bed, any other convenient arrangement may be resorted to without departing from the spirit of the invention. The elements may in fact be disposed vertically or longitudinally of the heating trough, or at any intermediate angle. In cases where steam or hot gas pipes are used, an arrangement similar to the arrangement of the cooling pipes in the cooling zones illustrated herein could be utilized. We generally prefer horizontal elements disposed crosswise to the trough becauses of simplicity of design and versatility of arrangement and ease of control in operation. We wish it to be understood, however, that our invention is not limited to the particular arrangements shown, the variety of operable arrangements which could be utilized being practically unlimited, and those arrangements which are actually illustrated being arrangements which we particularly prefer having regard principally to design considerations only.

The apparatus illustrated in Figure 6 is a modification of that shown in Figure 4, the heating section being divided into zones H and K, and the zone K being separated from the cooling section L by zoning devices consisting of the wedge-shaped weirs 60 and the underflow baffles 61 in accordance with a preferred embodiment of the zoning device described in Application No. 1801/53, filed 21st January 1953, and having strip resistor heating elements arranged in multiple banks or cribs. This apparatus operates in a manner similar to that illustrated in Figure 4, but it is designed for the somewhat higher rates of horizontal flow made desirable when using strip type resistor heating elements, the head loss from zone to zone at higher rates of flow being much less with this type of zoning device than with the type shown in Figure 4.

In order to illustrate how the apparatus may be adapted for the carrying out of any particular operation and the various factors entering into the design of the apparatus of the invention, the following explanation is given using as an example the calcination of alumina. From the explanation given those skilled in the art will have no difficulty in suitably arranging apparatus of the invention for use in other processes involving the heating of finely divided fluidizable solid material.

It is first of all necessary to have regard to the thermal characteristics of the material which is to be treated, and for purposes of illustration it will be assumed that the material to be heated is gibbsite and that it is in pure bone-dry condition when it is fed to the apparatus. Accurate thermal data for material of mineral origin is not usually available, but sufficiently accurate determination of the factors involved to enable rational design of apparatus may be made by dividing the temperature range through which the material is to be heated into ranges of say 100° F. and calculating the average amount of heat which will be required within each such temperature range. For purposes of the present illustration it is assumed that the gibbsite begins to decompose at 300° F., and it is assumed that the material is completely dehydrated at a temperature of 950° F. Within these two limits it is assumed that at 600° F. the conversion is 25% complete, and at 750° F. it is 75% complete.

The heat of reaction during the conversion may be taken for the reaction: $2Al(OH)_3 = Al_2O_3(\gamma) + 3H_2O(g)$ at 600° K. Since 600° K. (620° F) is close to the assumed 50% conversion point, for practical purposes it is possible to disregard the heat taken for heating the released water from the base temperature of 600° K. to the exit temperature. This assumption is further justified by the fact that in the apparatus of the invention the water of dehydration is discharged from the bed almost in the same place in which it is released from the molecule, and accordingly does not undergo further heating or cooling in the bed and does not cause further consumption of heat in the subsequent zones through which the bed flows.

Acting on the above assumptions, the necessary thermal data for design of suitable apparatus can readily be calculated and is tabulated in Table 1.

TABLE I.

CALCINATION OF ALUMINA.

Thermal data for the calcination of 1 (U.S.) ton gamma alumina from 1.530 ton Gibbsite dry basis

Temperature range of	Weight of system—means lbs. total	Heat requirements Q total Btu's	Heat required in 100° F. intervals Btu/100° F.	Kw—hrs required
230— 350	3,060	77,112	642.6	22.6
350— 600	2,927	611,247	6439.4	179.0
600— 750	2,530	991,609	6610.7	290.4
750— 950	2,132	556,865	2784.3	163.1
950—1050	2,000	52,000	520.0	15.2
1050—1250	2,000	104,000	520.0	30.5
1250—1950	2,000	364,000	520.0	106.6
Total 230—1950		2,756,833	*2576.7	807.4

*Average

The above data is represented in graphical form in Figure 9, the curve 90 being the heat requirement curve for the operation which is to be performed. It will be appreciated that similar curve could be prepared for any material which is fluidizable in finely divided form once the general thermal properties of the material have been ascertained.

The next stage in the design of a suitable apparatus is to determine what the capacity per unit of time is to be. Assuming that the heating elements are to be in the preferred form of electrical strip resistors inclined at an angle to the horizontal as above described, it is a simple matter to determine what the cross-sectional area of the fluidized bed should be to have the correct amount of fluidized solid material pass any given point in any given unit of time with a horizontal bed velocity in the neighbourhood of 5′ per minute, which, as explained above, is a suitable bed velocity when using strip type resistors.

The bed velocity being known and the specific heat of the material being known, it is a simple calculation to determine how much heat must be put in to the apparatus in order to have the material passing a given point at a temperature of 350° F. For the calcination of gibbsite, it is desirable at this point to insert a zoning device, preferably of the type illustrated in Figure 6.

By using the graph in Figure 9 it is a simple matter to determine the amount of heat required to raise the material to a temperature of 600° F. and the heating elements may be arranged and designed to introduce this quantity of heat. Similarly, by reference to Figure 9, it will be noted that within the temperature ranges between 600 and 750° slightly more heat will be required, while in the temperature range of from 750 to 950° considerably less heat must be inserted. Normally, it would be desirable to insert a zoning device in the apparatus slightly above the temperature of 950° since it is at this point that water ceases to be evolved by the material.

Depending upon what end product is desired, the material will then either pass into a cooling section, in which case gamma alumina is produced, or the material may be passed through a further heating zone and heated to a temperature of approximately 1950° F. to produce normal alumina. It will be seen from the graph in Figure 9, however, and from the data given in Table I that the heating from 950 to 1950° only takes approximately 19% of the total heat required for the operation.

Although the use of electrical resistors is quite feasible up to a temperature of 1950° F. or higher, particularly when silicon carbide heating elements are employed, heating by means of electrical resistor elements finds its most advantageous field of use at temperatures below 1000° F. Because electrical losses are apt to be greater in high temperature calcination, it is generally more economical to make use of radiant walls on either side of the tunnel which are heated from the outside by means of burners of one sort or another. It should be emphasized, however, that there are many cases where it may be desirable to use electrical resistor heating even at high temperatures because the advantages afforded may more than offset the less efficient use of electricity at these temperatures

On the basis of the foregoing data (which it will be appreciated is only

roughly correct), the calcination of gibbsite to a temperature of 1950° F. would involve the use of 2,750,000 Btu's and recovery of approximately 950,000 Btu's in the form of steam. The approximate overall heat consumption (minimum) therefore will be about 1,800,000 Btu's per ton. This compares with a consumption of approximately 3,500,000 Btu's per ton, which is the best data in connection with heat consumption for calcination of the same material in rotary kilns. Use of the present invention, therefore, affords the possibility of saving almost half of the heat necessary for carrying out the same operation in a conventional manner.

While mention has been made of the treatment of alumina and low grade sulphide ores according to the invention, it will be appreciated that such materials are given only as a means of illustration. The invention may be applicable to the treatment of any material which is capable of being fluidized in finely divided form. In this connection, it should be pointed out that many materials in finely divided form will tend to sinter when they are heated or will form specific structural agglomerations, sometimes referred to as "aero-thixotropic gels", when an attempt is made to fluidize them. Other materials will form agglomerates and, of course, all such materials are not suitable for treatment according to the present invention. Materials which are capable of fluidization are well known in the art and a great number of them are listed in the literature. On the other hand, it is a matter of a very simple experiment to determine whether or not any particular finely divided material is capable of being fluidized.

In the specification and in the appended claims we use the term "fluidizable", and it should be understood that in using this term we intend to include all solid materials which when in suitable finely divided form are capable of successfully being fluidized by the passage upwardly therethrough of a controlled flow of a suitable fluidizing medium and which will continue to be fluidizable throughout the operation which is being carried out. By the use of such term we intend to exclude any materials which cannot be satisfactorily fluidized in the manner known in the art and materials which, although they may be fluidizable in the cold state, will undergo physical changes during heating, rendering them no longer capable of being satisfactorily fluidized.

Various arrangements of the apparatus of the invention which may be resorted to in designing a plant for the carrying out of any particular operation will be apparent to those skilled in the art. One such arrangement suitable for the calcination of alumina is given by way of illustration in Figure 10. It will be seen that the plant consists of three heating sections P, Q and R, and two cooling sections S and T arranged side by side with the material entering the plant through the chute 101 and leaving it by the chute 102. Heat is supplied to the material by means of the multiple banks of strip resistors 103 of the type described in connection with the apparatus illustrated in Figures 5, 6 and 7, while the sensible heat in the hot, calcined product is largely recovered by means of a liquid cooling medium flowing through the cooling coils 104 in the cooling sections S and T. The electrical connections are conveniently mountable above the apparatus, as are connections for the circulation on the cooling medium.

The heat economy aspect of the invention will be at once apparent since there will be no heat losses through the intervening walls 105, 106, 107 and 108, while the compactness of the arrangement offers a considerable advantage in saving of plant space. The plant illustrated in Figure 10 is, however, merely an example of one of many arrangements which might be made to suit particular circumstances, and is merely given to illustrate how further heat economies can be achieved and how an extremely compact arrangement of a plant may be achieved when using the apparatus according to the present invention.

While most of the foregoing has been directed to treatment of materials on a large scale, there are many operations of a small scale nature to which the invention may be applied. For instance, in the production of pigments, particularly iron oxide pigments, exceedingly close control of the temperature to which the pigment is heated and time of such heating is most important. The present invention affords such exact control while at the same time providing for continuous operation. Other suitable small scale applications of the invention will be obvious to those skilled in the art.

In view of Section 9 of the Patents Act, 1949, attention is directed to the specification and claims of United Kingdom Patent No. 693,868.

What we claim is:—

1. Method of treating finely divided fluidizable solid material comprising forming and maintaining a deep fluidized bed of said material in horizontal flow and transmitting heat to said material by means of heating elements in direct contact therewith at successive stages of its

horizontal flow in varying predetermined quantities and at varying predetermined temperatures.

2. Method of treating finely divided fluidizable solid material to carry out a series of changes in composition thereof; comprising forming and maintaining in horizontal flow a deep fluidized bed of said material and transmitting heat to successive zones of said horizontally flowing fluidized bed by means of heating elements in direct contact therewith in the quantities and at the temperatures required to accomplish desired reactions in each of said successive zones.

3. Method of treating finely divided fluidizable solid material, comprising forming and maintaining a deep fluidized bed in horizontal flow over a series of heating elements. adjusting and maintaining the rate of horizontal flow of said material and the temperature of and number of said heating elements so as to vary the temperature of and heat transfer to the solid material in successive zones along the direction of flow, and adjusting and maintaining the amount of fluidizing medium provided to each zone of the fluidized bed so as to maintain optimum fluidized conditions throughout the whole of said horizontally flowing fluidized bed.

4. A method as defined in Claim 1, wherein the quantity of heat is supplied to said material within predetermined temperature ranges substantially in conformity with the heat requirements of said material over said temperature ranges for the operation being performed.

5. A method of heating finely divided, fluidizable solid material, comprising forming and maintaining a deep, fluidized bed of said material; flowing said bed horizontally past a plurality of heating elements comprising electric strip resistor elements horizontally disposed transversely to said bed, said strip resistor elements being inclined at an angle between 75° and 45° to the horizontal with the downstream edges thereof being uppermost; and maintaining a horizontal rate of flow of said bed which is sufficiently high to provide smooth flow conditions within said bed.

6. A method as defined in Claim 5, in which the horizontal rate of flow of said bed is maintained between 0.2 and 5 feet per minute.

7. Apparatus for heating finely divided, fluidizable solid material, comprising means for providing a deep horizontally flowing fluidized bed of said material, said bed having a height substantially greater than the width thereof; means for continuously introducing material to one end of said bed; means for continuously withdrawing material from the other end of said bed; and heat transfer means in direct contact with said bed and arranged to transmit heat to said material progressively to heat it as it advances horizontally within said bed: said heat transfer means being arranged to transmit to said material predetermined quantities of heat within portions of said bed where the temperature of said material is within predetermined ranges.

8. Apparatus as defined in Claim 7, in which means are provided for independent regulation of the amount of fluidizing medium supplied to particular portions of said bed.

9. Apparatus as defined in Claim 7, in which said heat transfer means comprises a plurality of heating elements disposed within said bed.

10. Apparatus as defined in Claim 7, in which said heat transfer means comprises a plurality of heating elements horizontally disposed transversely within said bed.

11. Apparatus as defined in Claim 7, in which said heat transfer means comprises a plurality of heating elements disposed within said bed and arranged in greater density within portions of said bed where endothermic changes in said material are occurring.

12. Apparatus as defined in Claim 7, in which said heat transfer means comprises a plurality of heating elements disposed within said bed and arranged in lesser density within portions of said bed where exothermic changes in said material are occurring.

13. Apparatus as defined in Claim 7, in which said heat transfer means comprises a plurality of heating elements disposed within said bed in a density which varies lengthwise of the bed in accordance with variation in the heat capacity of the material undergoing treatment as it proceeds along the bed.

14. Apparatus as defined in Claim 7, in which said heat transfer means comprises a plurality of electrical resistor elements.

15. Apparatus as defined in Claim 7, in which said heat transfer means comprises a plurality of electrical resistor elements horizontally disposed transversely within said bed.

16. Apparatus as defined in Claim 15, in which said electrical resistor elements are strip resistors, and the strips are each inclined at an angle to the horizontal, the downstream edge of said resistors being uppermost.

17. Apparatus as defined in Claim 16 in which said strip resistors are inclined at an angle to the horizontal of from 75° to 45°.

18. Apparatus as defined in Claim 17, in which said strip resistors are arranged in a plurality of vertical banks between vertical distributor bars, the latter having suitable power connections entering the apparatus from the top thereof.

19. Apparatus as defined in Claim 15, in which said resistor elements are arranged in groups of vertical banks, each said group comprising distribution bars for each vertical bank of resistors; laterally spaced apart and longitudinally disposed branch bus-bars for each side of said group and positioned within the apparatus above the bed, each of said branch bus-bars being connected to the distribution bar on one side of each of said banks; and a bus-bar for each branch bus-bar arranged to connect the latter to a suitable power source situated above the apparatus.

20. Apparatus as defined in Claim 7 comprising means for dividing said bed into independent zones, said means being arranged across the bed at at least one point along the length thereof corresponding to a predetermined temperature of the material within said bed and means for separate collection of gases rising from said bed in each of said zones.

21. Apparatus as defined in Claim 20, in which independently controllable fluidizing media supplies are provided for each of said independent zones.

22. In apparatus for heating finely divided, fluidizable solid material, which comprises means for providing a deep, horizontally flowing fluidized bed of said material, and means for transmitting heat to said material in said bed progressively to heat it as it advances horizontally within said bed; heating means comprising an electrical strip resistor horizontally disposed transversely within said bed, and inclined at an angle to the horizontal, the downstream edge of said strip resistor being uppermost.

23. Apparatus as defined in Claim 22, in which the angle at which said strip resistor is inclined to the horizontal is between 75° and 45°.

24. A method of heating finely divided, fluidizable solid material substantially as described.

25. Apparatus for heating finely divided, fluidizable solid material substantially as described.

26. Apparatus substantially as illustrated in the accompanying drawings.

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Agents for the Applicants.

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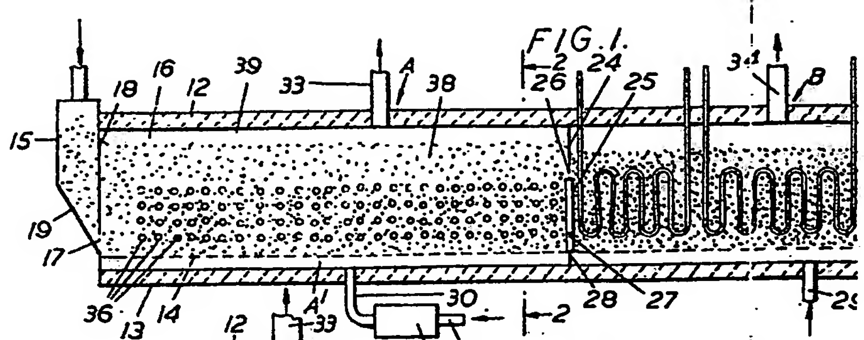
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

FIG. 1.



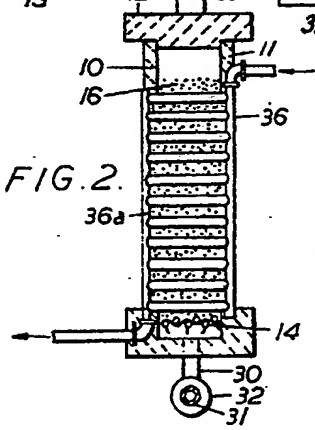


FIG. 2.

FIG. 3.

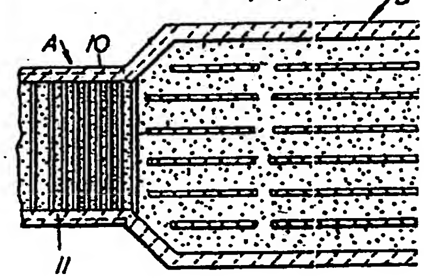
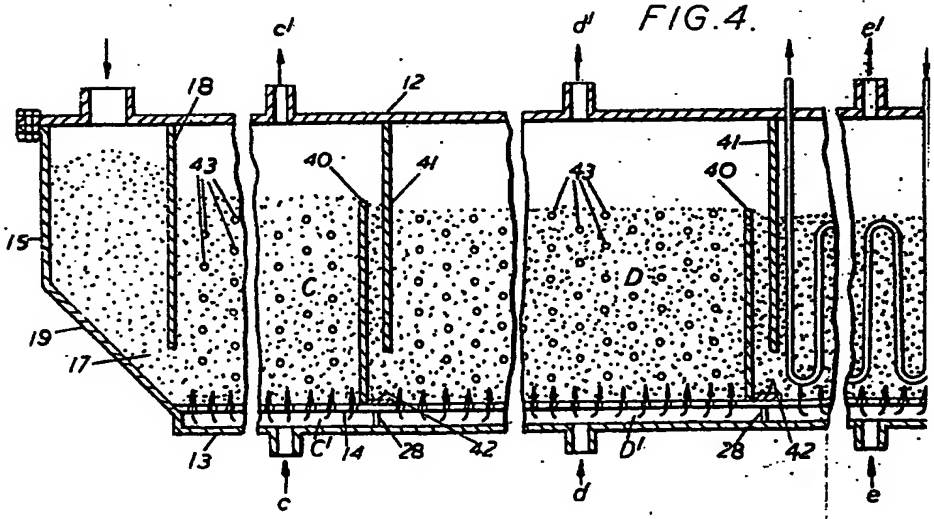


FIG. 4.



736,036 COMPLETE SPECIFICATION

3 SHEETS

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SHEET 1

G.1.

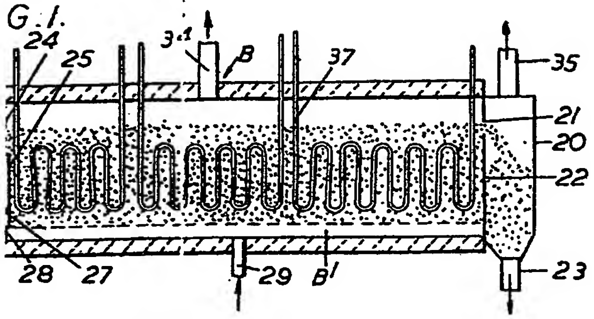


FIG.3.

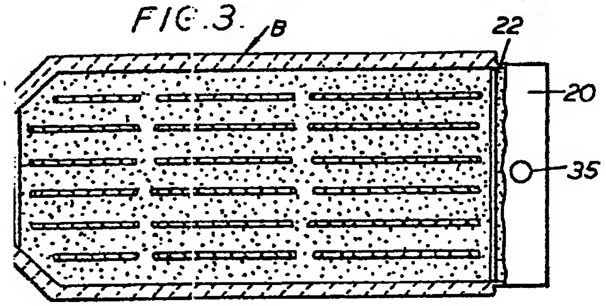
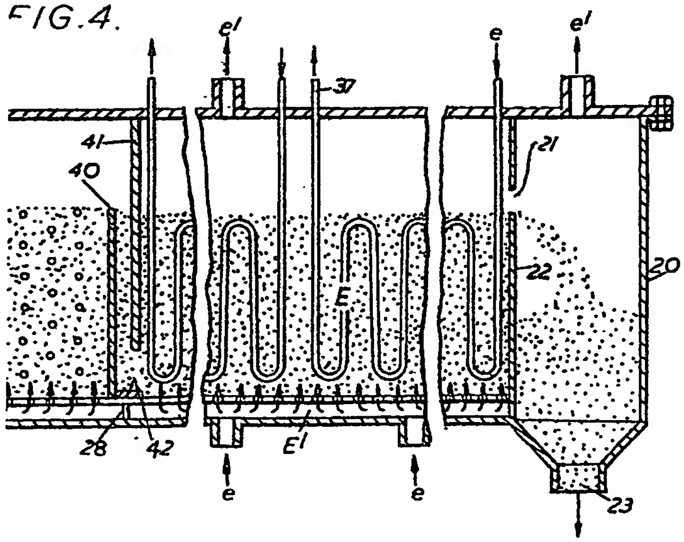


FIG.4.



736,036 COMPLETE SPECIFICATION
3 SHEETS
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SHEET 1

FIG. 1.

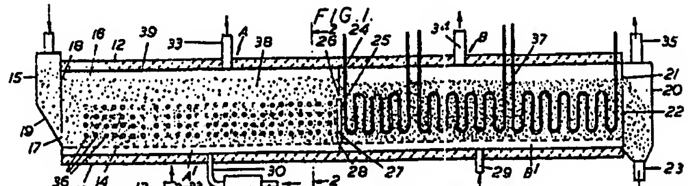
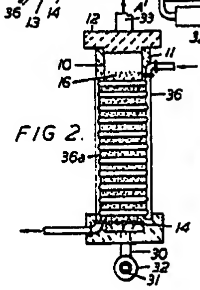


FIG 2.



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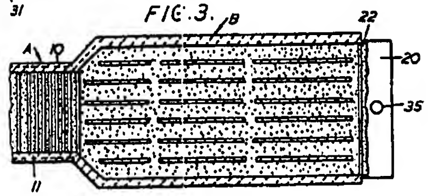


FIG. 4.

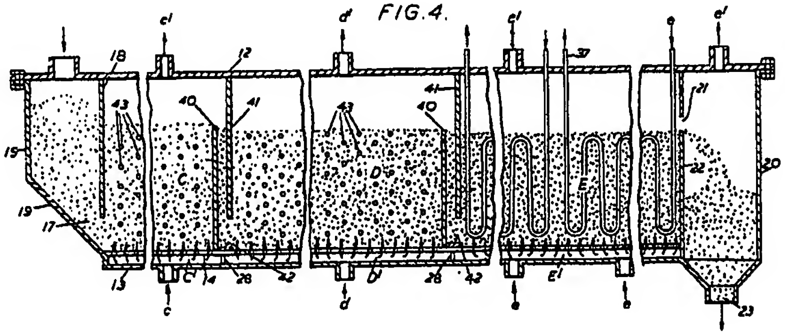
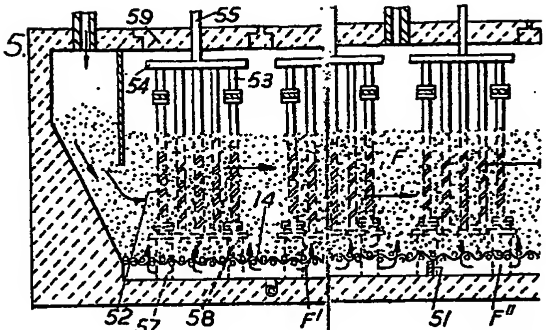


FIG.5



FIG

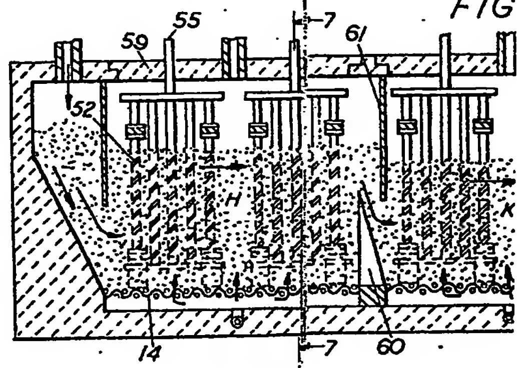


FIG.7.

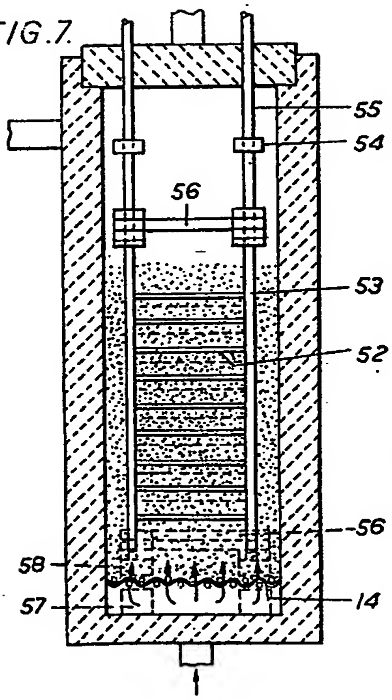
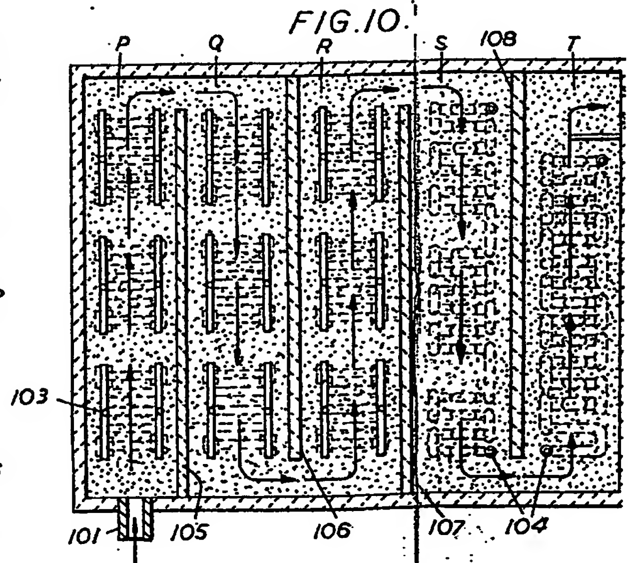


FIG.10.



736,036 COMPLETE SPECIFICATION

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SHEET 2

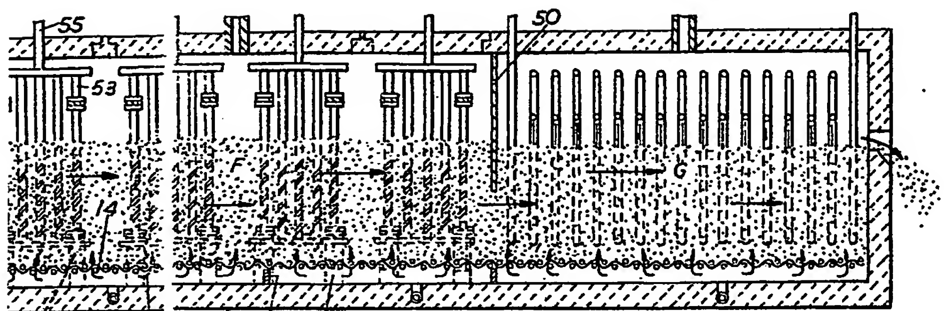


FIG.6.

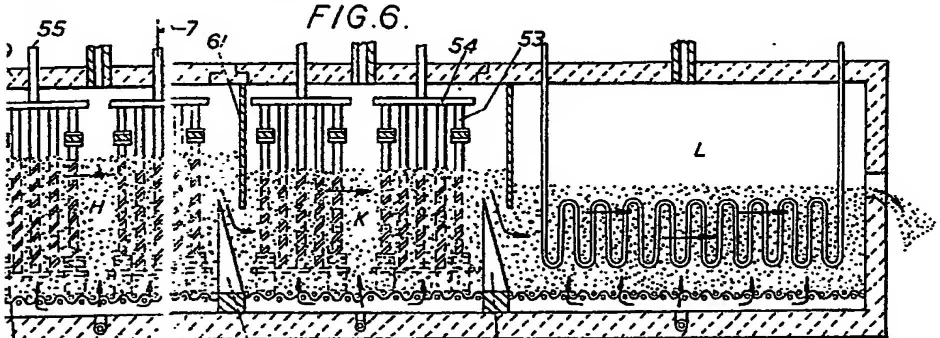
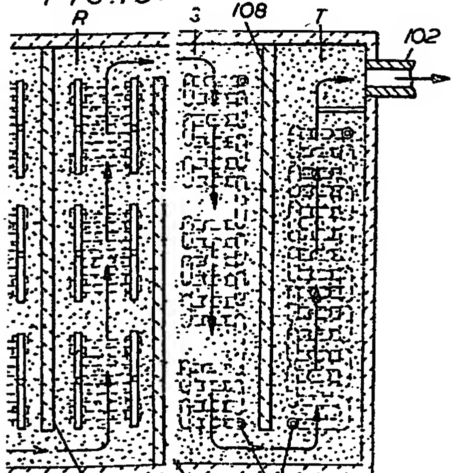


FIG.10.



736,036 COMPLETE SPECIFICATION
3 SHEETS This drawing is a reproduction of the Original on a reduced scale.
SHEET 2

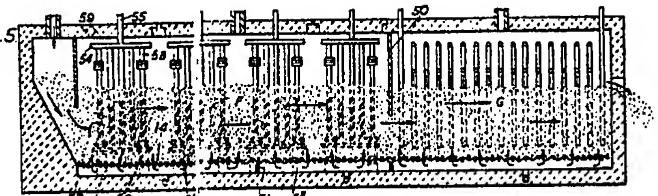
FIG.5


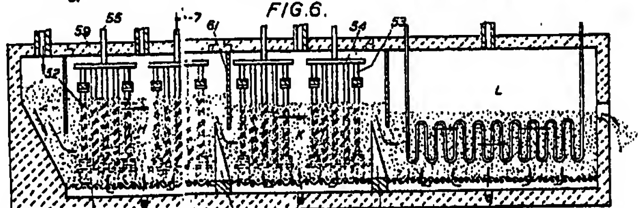
FIG.6.


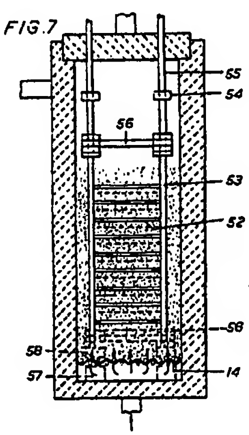
FIG.7


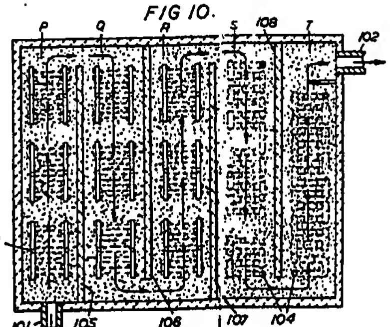
FIG 10.


FIG. 8.

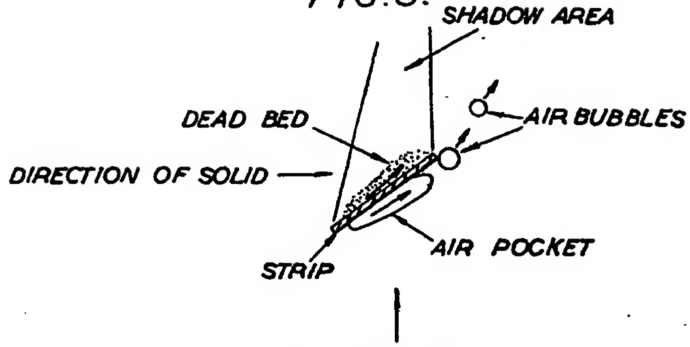
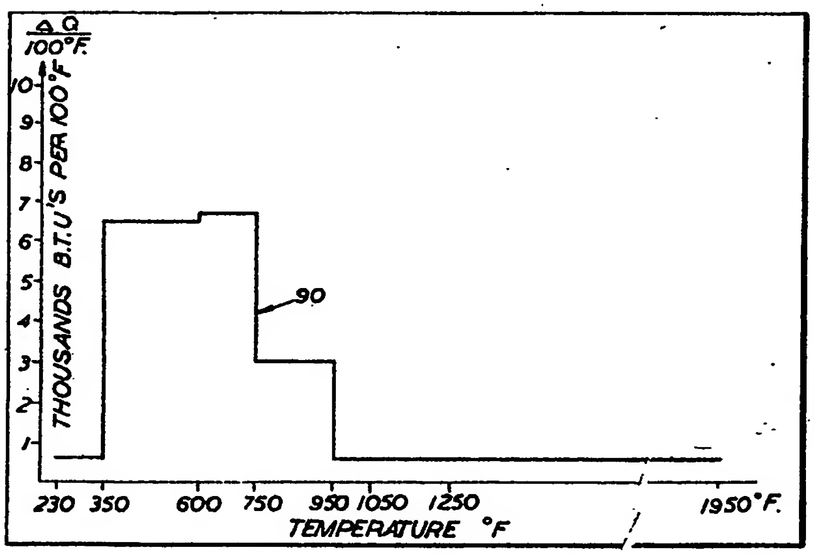

SHADOW AREA
AIR BUBBLES
DEAD BED
DIRECTION OF SOLID
AIR POCKET
STRIP
DIRECTION OF AIR

FIG. 9.


ΔQ / 100°F.
THOUSANDS B.T.U'S PER 100°F
10
9
8
7
6
5
4
3
2
1
90
230
350
600
750
950
1050
1250
1950°F.
TEMPERATURE °F